Space Technology Research Grants

Uncovering the Chemical Processes during Atmospheric Entry of a Carbon/Phenolic Ablator: Laboratory Studies by In Situ Mass Spectrometric and Molecular Beam Techniques

Completed Technology Project (2015 - 2018)

Project Introduction

Several advanced thermal protection system (TPS) materials currently under development, such as conformal and woven systems, leverage the porous ablator technology developed for phenolic impregnated carbon ablator (PICA), a binary-constituent composite resin infiltrated carbon fiber substrate system. Current ablation models assume thermodynamic equilibrium chemistry to estimate the recession rate and temperature response, and these models are known to be deficient because they over predicted the recession rate, for example, during the Mars Science Laboratory entry into the Martian atmosphere. Clearly, non-equilibrium chemistry is important in such environments; therefore, non-equilibrium models must be built on a fundamental understanding of the relevant non-equilibrium chemical kinetics and dynamics, which may be obtained from in situ measurements of chemical processes during pyrolysis of PICA-class materials under controlled, non-equilibrium conditions. Validating the models with such high quality laboratory data will enable optimized risk and margin recommendations for a whole generation of future NASA and commercial space missions. The objective of this effort is to transform our understanding of the decomposition chemistry of carbon/phenolic composite ablator materials using advanced techniques that are well established in the field of reaction dynamics but have not previously been applied to understand the decomposition mechanisms of these materials in an atmospheric entry environment. To achieve the objective, we will measure time-dependent yields of volatile products during the pyrolysis of a phenolic resin and a carbon/phenolic composite, and we will study the kinetics and dynamics of the heterogeneous reactions of ablation products and representative boundary gases (from Earth and Mars environments) with char and with preform carbon surfaces. We will also investigate the erosion kinetics of pure phenolic resin and a carbon/phenolic composite at high temperatures in a simulated boundary-gas environment. The focus materials will be PICA, obtained from Fiber Materials, Inc., and the separate preform carbon and phenolic resin components of this composite. The experiments will utilize a molecular beam apparatus with a highly sensitive, triply differentially-pumped mass spectrometer. The mass spectrometer will be used to detect pyrolysis products of hot materials and reactive products when controlled material surfaces are bombarded with beams of specific reagent gases. Pyrolysis products will be detected from surfaces with temperatures from ambient to about 1500 K, while beam-surface reactive products may be detected from surfaces with temperatures up to about 2200 K. For kinetic studies of erosion, surfaces at various temperatures will be bombarded by beams containing pure O_2, N_2, or CO_2 and mixtures containing O, O_2, CO, CO_2, N, and/or N_2 in mole ratios to be specified. Exposed surfaces will be probed by scanning electron microscopy (SEM). The PI intends to work closely with NASA researchers to ensure that the experiments conducted will generate data that will validate ablation models under development.

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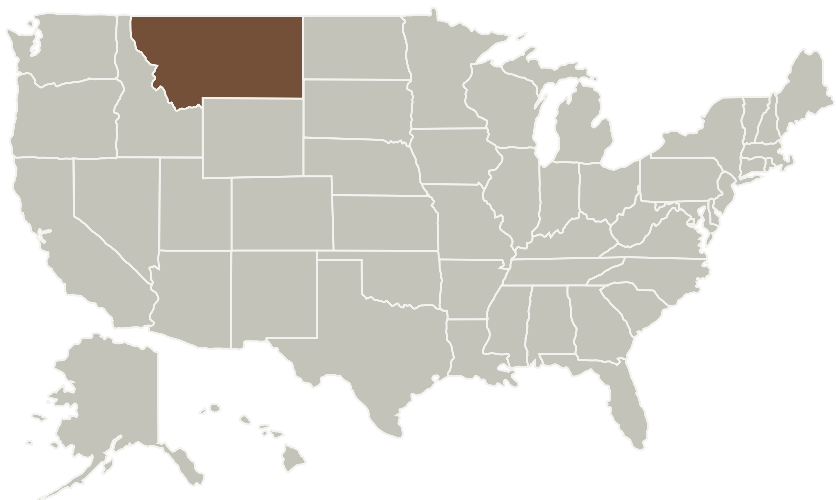
Anticipated Benefits

Validating the models with such high quality laboratory data will enable optimized risk and margin recommendations for a whole generation of future NASA and commercial space missions. The objective of this effort is to transform our understanding of the decomposition chemistry of carbon/phenolic composite ablator materials using advanced techniques that are well established in the field of reaction dynamics but have not previously been applied to understand the decomposition mechanisms of these materials in an atmospheric entry environment.

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
Montana State University - Bozeman	Lead Organization	Academia Alaska Native and Native Hawaiian Serving Institutions (ANNH)	Bozeman, Montana

Primary U.S. Work Locations
Montana

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Organization:

Montana State University - Bozeman

Responsible Program:

Space Technology Research Grants

Project Management

Program Director:

Claudia M Meyer

Program Manager:

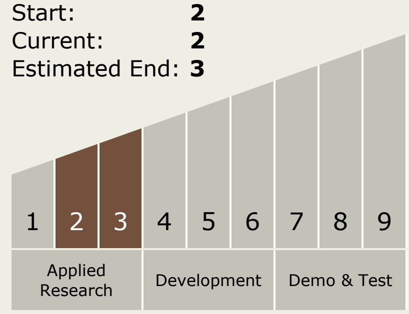
Hung D Nguyen

Principal Investigator:

Timothy Minton

Technology Maturity (TRL)

Start: **2**
Current: **2**
Estimated End: **3**



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Project Website:

https://www.nasa.gov/directorates/spacetech/home/index.html

Technology Areas

Primary:

- TX06 Human Health, Life Support, and Habitation Systems
  - └ TX06.1 Environmental Control & Life Support Systems (ECLSS) and Habitation Systems
    - └ TX06.1.1 Atmosphere Revitalization

Target Destination

Foundational Knowledge